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ABSTRACT

This study focused on the knowledge of six outstanding science students who solved an osmosis problem meaningfully. That is, they used appropriate and substantially accurate conceptual knowledge to generate an answer. Three generated a correct answer; three, an incorrect answer. This paper identifies both the accurate and inaccurate conceptions about osmosis of each correct and incorrect solver. The investigation consisted of a presolving clinical interview, think-aloud solving of the problem, and retrospective report of the solving. Of the 12 accurate conceptions identified here, 2 were especially important in enabling these solvers to generate a correct answer. Of the eight inaccurate conceptions, either of two blocked a correct answer. Four, however, accompanied (and could therefore be concealed by) a correct answer. Teachers could use this information to make a meaningful solving of this problem accessible to more students and to identify more effectively students' inaccurate conceptions about osmosis. (Contains 23 references.) (Author)

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Accurate and Inaccurate Conceptions About Osmosis That Accompanied Meaningful Problem Solving

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Atlanta, GA, April 17, 1993

ACCURATE AND INACCURATE CONCEPTIONS ABOUT OSMOSIS THAT ACCOMPANIED MEANINGFUL PROBLEM SOLVING

Abstract

This study focused on the knowledge of six outstanding science students who solved an osmosis problem meaningfully. That is, they used appropriate and substantially accurate conceptual knowledge to generate an answer. Three generated a correct answer; three, an incorrect answer. This paper identifies both the accurate and inaccurate conceptions about osmosis of each correct and incorrect solver. The investigation consisted of a presolving clinical interview, think-aloud solving of the problem, and retrospective report of the solving. Of the 12 accurate conceptions identified here, two were especially important in enabling these solvers to generate a correct answer. Of the 8 inaccurate conceptions, either of 2 blocked a correct answer. Four, however, accompanied (and could therefore be concealed by) a correct answer. Teachers could use this information to make a meaningful solving of this problem accessible to more students and to identify more effectively students' inaccurate conceptions about osmosis.

Accurate and Inaccurate Conceptions About Osmosis That Accompanied Meaningful Problem Solving

Introduction

Osmosis is a universal concept in biology curricula that is fundamental for understanding water balance and transport systems in plants and animals. It is the spontaneous movement of water across a selectively permeable membrane in response to the difference in the free energy of water across the membrane (Gayford, 1984; Hutchinson & Sutcliffe, 1983). The essential attributes are the selectively permeable membrane, concentration gradient, and movement of water (Friedler, Amir, & Tamir, 1987).

Yet osmosis is a difficult concept for high school students to understand (Friedler et al., 1985, 1987). Scottish biology students rated water relations including osmosis to be the most difficult of 15 topics in biology (Johnstone & Mahmoud, 1980a). Okeke and Wood-Robinson (1980) found that most Nigerian higher ability students showed little or no grasp of the concept at the end of an introductory biology course. Thus high school students in various educational contexts have had difficulty understanding osmosis.

Problem solving can enable students to understand such concepts better (Novak, 1977a). The problem solving, however, should be meaningful. That is, conceptual knowledge (rather than a rote execution of the procedure) should drive the solving. Moreover, the conceptual knowledge should be accurate, i.e., compatible with the knowledge of contemporary scientific communities, and appropriate to the problem. Meaningful problem solving is, however, a relative term (Stewart, 1982). For the study undertaken here, a solving was considered meaningful as long as the conceptual knowledge was <u>substantially</u> accurate. Unless the conceptual knowledge is <u>completely</u> accurate, however, a meaningful solving can generate an incorrect answer.

Many students do not have the conceptual knowledge they need to solve a science problem meaningfully. In fact, they may not have had even the opportunity to construct this knowledge because their teachers were unaware of some of the subtle pieces. As experts, teachers have a substantial amount of tacit knowledge (Reif, 1983). Thus teachers may first need to identify pieces of knowledge that are useful for meaningfully (and correctly) solving a particular science problem.

Moreover, students may have inaccurate conceptions that hinder their ability to solve a particular problem meaningfully and correctly. A teacher, therefore, also needs to identify inaccurate conceptions that could block a correct answer. Similarly, a teacher should identify inaccurate conceptions that a solver could have despite having meaningfully generated a correct answer. A correct answer could conceal the presence of such inaccurate conceptions.

Thus the purpose of this qualitative study was to identify, for a particular osmosis problem, some (a) accurate conceptions about osmosis that could be useful for generating a meaningful solving (and a correct answer), (b) inaccurate conceptions about osmosis that could block a correct answer, and (c) inaccurate conceptions about osmosis that could accompany (and be concealed by) a meaningful solving and a correct answer. Teachers could use this information to make a meaningful solving of the problem accessible to more students and to identify more effectively students' inaccurate conceptions about osmosis.

An osmosis problem was selected from Baker and Allen (1982), a college text for general biology. The problem statement was then simplified for this study (see Figure 1). The problem condition has been widely

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Insert Figure 1 about here

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displayed in high school biology texts as an example of a typical osmotic system (for instance, see Otto & Towle, 1985; Schraer & Stoltze, 1987). Moreover, various researchers have used this osmometer-like system to explore students' conceptions about osmosis (Johnstone & Mahmoud, 1980b; Murray, 1983).

To increase the chances for a meaningful solving of this problem, the high school students recruited for this study had to be outstanding for both their scientific conceptual knowledge and interest in problem solving. Moreover, they had to be unfamiliar, i.e., unaware of any prior experiences, with the problem condition. Several researchers claim that those who solve an unfamiliar variation of a known type of problem rely on conceptual knowledge rather than on a rote execution of the solving procedure (Greeno, 1978; Novak, 1977b; Novak, Gowin, & Johansen, 1983; Wertheimer, 1959). Thus, for this study, the solving procedures presumably would be linked to the solvers' conceptual knowledge.

For those who based their solving procedure on substantially accurate conceptual knowledge about osmosis, i.e., for the meaningful solvers, the focus questions then were:

1. What are some of the accurate conceptions about osmosis of those who generated a correct answer? of those who generated an incorrect answer?

2. What are some of the inaccurate conceptions about osmosis of those who generated a correct answer? of those who generated an incorrect answer?

Thus this paper presents lists of accurate and inaccurate conceptions about osmosis that accompanied six outstanding science students' meaningful solvings of a problem about a typical osmotic system. The list of accurate conceptions makes explicit pieces of knowledge that may be tacit for many teachers. In fact, some of these pieces are not even mentioned in many high school biology texts (Friedler et al., 1985). Presumably, these pieces of knowledge could help other students to solve this problem meaningfully (and correctly) and to understand osmosis better. Likewise, the inaccurate conceptions listed here may be hindering other students from understanding osmosis better. In fact, outstanding science students have been found to have some of the same inaccurate conceptions that typify most science students (Peters, 1982). Thus the inaccurate conceptions listed here may even be quite prevalent.

Method

Data Collection

Science teachers in five suburban public high schools near New York City identified students who had outstanding scientific conceptual knowledge and an interest in problem solving. Sixteen students agreed to participate. All were studying science and had completed at least two years of high school science, including one year of biology. For each, the investigation began with a clinical interview, followed directly by a think-aloud solving of the problem and the solver's retrospective report of the solving. Thus the investigation generated oral data, which were audiorecorded and transcribed, and a pencil-and-paper answer.

A set of propositions was compiled from the information about osmosis in 34 college texts for general biology. Interview probes, devised to elicit this information, were then refined over the course of 12 pilot interviews. Ultimately, 16 research interviewees were shown diagrams of several osmotic systems (different from the problem condition) and were asked to predict and justify the outcomes of various manipulations of the systems. Accurate and inaccurate conceptions about osmosis were then identified from these data.

The think-aloud solvings, conducted according to the advice and cautions of Ericsson and Simon (1984), generated both a protocol, i.e., transcript of the solving, and an answer in the form of a graph. Protocols were assessed to determine whether the solvings were meaningful, and if so, the graphs were assessed to determine whether they were correct.

Finally, the retrospective reports were used to clarify the think-aloud solvings, including the intended meaning of the graphs, and to determine whether any of the solvers were familiar with the problem condition. Solvers were asked to recall problems they had tried to solve and laboratory apparatus they had encountered that had a system like the problem condition.

Two of the 16 recognized the osmometer-like system in the problem condition, specifically the selectively permeable membrane and the tube-like stem of the funnel. None of the 14 others, however, could recollect a system that seemed to them to match the problem condition. Moreover, when asked to describe the most similar system they could remember, only two of the 14 described an osmotic system. One described a U tube, and the other, a selectively permeable sack, systems featured during the interview. Thus 14 of the 16 were found to have been unfamiliar with the problem condition. Only their data were accepted for this study.

Data Analysis

Identifying a meaningful solving. The protocols and retrospective reports of these 14 solvers were evaluated for meaningfulness. A meaningful solving first had to be based on conceptual knowledge. That is, the solver had to use an understanding of the problem condition to rationalize changes in the solution level.

Moreover, the solver had to realize that the problem was about osmosis and use at least substantially accurate conceptual knowledge about osmosis to predict and rationalize the movement of water into the funnel. That is, during the think-aloud solving or retrospective report, the solver had to (a) predict the movement of water into the funnel (or the rise of the solution level in its stem) and (b) refer to the permeability of the membrane or the concentration difference when rationalizing that change. Thus a solving could be considered meaningful even if the solver thought that the rate of osmosis was constant or that the system could never reach an osmotic equilibrium. For each solving classified as meaningful, the graph was evaluated as either correct or incorrect, and the solver's accurate and inaccurate conceptions about osmosis were identified from the interview transcript.

Evaluating the meaningful solvers' answers. Each meaningful solver's graph was compared to a model graph that had been constructed in accord with textbook discussions of osmometer-like systems (see Figure 2).

Insert Figure 2 about here

An answer was considered correct if it had these attributes of the model graph:

1. The horizontal axis represented time, and the vertical axis represented the level of the solution.

2. The slope of the graph continuously decreased to zero and then remained constant.

Alternatively, an answer showing an equivalent graph but with the axes interchanged was also considered correct. Other answers were considered incorrect.

Identifying meaningful solvers' accurate conceptions about osmosis. The set of propositions compiled from the biology texts was revised so that the form of the propositions more closely matched the typical expressions of the interviewees. This set of revised propositions then became the List of Accurate Conceptions About Osmosis that was used to inventory each meaningful solver's accurate conceptions about osmosis (see Table 1).

Insert Table 1 about here

The interview transcript for each meaningful solver was analyzed according to the advice of Pines (Pines, Novak, Posner, & VanKirk, 1978; Posner & Gertzog, 1982), that is, for the substance rather than the literal statement of each accurate conception. Meaningful solvers were credited with knowing an accurate conception if they expressed its substance at most of the appropriate times. If they ever contradicted the substance of the conception, they had to have positively affirmed its soundness by the end of the interview to be credited with the conception.

<u>Identifying meaningful solvers' inaccurate conceptions about osmosis</u>. A list of inaccurate conceptions about osmosis was compiled from meaningful solvers' discrepant responses to interview probes for accurate conceptual knowledge (see Table 2, List of Inaccurate Conceptions About Osmosis). This list was

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Insert Table 2 about here

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then used to inventory each meaningful solver's inaccurate conceptions about osmosis.

For solvers to be credited with an inaccurate conception, they had to have either stated its substance or made a discrepant explanation, interpretation, or prediction that could be rationalized by such a conception. If they ever contradicted the substance of the conception, they had to have positively affirmed its soundness by the end of the interview to be credited with the conception.

Results

Only the data from the 14 solvers who were unfamiliar with the problem condition were transformed for this study. All 14 generated an answer. Only 6, however, solved the problem meaningfully. In this section, the six meaningful solvers are identified, their graphs are classified as either correct or incorrect, and their accurate and inaccurate conceptions about osmosis are listed in tables. Moreover, excerpts from some of their verbal reports highlight the criteria for meaningfulness, the intended meanings of their graphs, and differences in the ways they conceptualized osmosis.

The Meaningful Solvers

The six meaningful solvers are designated here as MG, NK, GT, JD, EB, and RG. They all predicted the movement of water into the funnel. NK, however, referred to the permeability of the membrane when rationalizing that movement: "The membrane is permeable only to water. Therefore only water can go in or out. Therefore, since I have less water inside the thistle tube and more water in the beaker, therefore pure water will go into the thistle tube."

On the other hand, JD referred to the concentration difference. He explicitly linked the concentration difference to osmotic pressure: "The pure water's gonna diffuse into the thistle tube... [where there's a] dilute sugar solution, so there won't be much osmotic pressure."

The Meaningful Solvers' Answers

Three meaningful solvers each generated a correct answer; three, an incorrect answer. Moreover, for all six, the intended meanings of their graphs were consistent with the conventional interpretation.

Correct answers. MG and NK each generated an answer having the two attributes of the model graph. GT generated an equivalent graph but with the axes interchanged. Accordingly, they each described a system that reaches an osmotic equilibrium as the rate of osmosis decreases: For example, from NK's protocol:

> It would go in quickly as soon as possible and as quickly, and then it would start to slow down... As time goes on, the water will level off and become constant and then, then no more will go in.

Incorrect answers. JD and EB each generated a graph with a continuously decreasing slope, but the graphs had a horizontal asymptote rather than a horizontal tangent (See Figure 3). Accordingly, they

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Insert Figure 3 about here

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each described a system in which the rate of osmosis decreases, but an osmotic equilibrium is never reached. For example, from JD's retrospective report:

> It'll slow down, which is why we get a uhm curved graph instead of just a straight graph toward the uhm equilibrium state... It's going to approach an equilibrium state, but it'll never quite reach it.

Finally, RG generated a graph with a discontinuous slope. The initial portion of the graph had a constant positive slope; the latter portion, a zero slope (see Figure 4). Accordingly, RG described a system in which

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Insert Figure 4 about here

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the rate of osmosis is constant until an osmotic equilibrium is reached: "It would go up the stem at like, at an equal rate 'til it reached its uhm, a point that it was gonna... stay that way.... That's where it stayed."

<u>The Meaningful Solvers' Conceptions About Osmosis</u>

The group of six meaningful solvers expressed all 12 accurate conceptions derived from the set of propositions. Additionally, the group expressed a total of 8 inaccurate conceptions about osmosis. Table 3 is an inventory of each correct and incorrect solver's accurate conceptions; Table 4, of their inaccurate conceptions. Thus Tables 1 and 3 address

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Insert Table 3 about here

Insert Table 4 about here

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the first focus question; Tables 2 and 4, the second focus question.

Finally, excerpts from the clinical interviews highlight important differences in the ways the meaningful solvers conceptualized osmosis. For example, JD described osmosis as the net movement of water that results from the random motion of molecules crossing the membrane both ways. Thus he explained an osmotic equilibrium:

> Some of the pure [water] molecules are gonna go through the membrane, but the same number are going to come out of the membrane so there's no net change.... The rates of [the] two reactions are equal to each other... Even though individual molecules would be changing, the net change would

> be zero.... The random motion of mole--molecules: Some water molecules will go through the membrane ... but by random motion, some of them are going back.

On the other hand, NK visualized osmosis as a one-way teleological/anthropomorphic movement. She not only consistently described each osmotic system as something that "will try to go towards an equilibrium," but she used such anthropomorphic constructs to explain why the rate of osmosis slows down:

> Say if you're running toward a brick wall, and you're running a 20-yard dash-- 50-- 100 yard dash, and you're running in a brick wall, you'd start out going really fast, but you know you're gonna get there so you're gonna kind of slow down so you don't smash into the thing.

Accordingly, NK came to challenge the relevance of the concentration difference she had heretofore accepted: "How in the world could the water in here be able to tell that there's salt in there [in the solution across the membrane]?" She then constructed her own model of osmosis in which the amounts of water across the membrane, rather than the concentrations, were relevant: "It doesn't matter about your concentration.... Because it doesn't matter how much solute you have. It's the amount of water." JD, on the other hand, grasped the relevance of a concentration difference: "There's less push as it were if there were a lower concentration because there's less of a difference in osmotic pressure."

JD and NK also had different ideas about the conditions necessary for an osmotic equilibrium. JD believed that the concentrations of water across the membrane had to be equal. Thus he could foresee an osmotic equilibrium only in systems where two solutions, rather than a solution and pure water, were juxtaposed:

> It would be in equilibrium if there are two solutions... a solution instead of pure water. The system would be in equilibrium when the concentrations in both sides were the same. Then the rate of osmosis from solution A to solution B would equal the rate of osmosis from solution B to solution [A] so there'd be no net change in either solution.

On the other hand, NK believed that the amounts, rather than the concentrations, had to be equal:

> The condition that allows that equilibrium is uhm... the fact that there's the same amount of water on one side and the same amount of water on side-- the left.... Because you have the same

amounts of water on both sides, you won't have flow.

Although they each had an inaccurate conception about the conditions necessary for an osmotic equilibrium, NK could still generate a correct answer to the problem. She could foresee the passage of enough water to effect equal amounts. No quantity of water, however, could effect equal concentrations. Thus NK, but not JD, could predict an osmotic equilibrium and generate a correct answer.

Discussion

The results of this study made explicit some of the accurate and inaccurate conceptions about osmosis of six outstanding science students who solved the problem under study meaningfully. All of the accurate conceptions listed in this study could have been used to generate a meaningful solving. Two, however, seem to have been especially important in enabling these solvers to generate a correct answer. On the other hand, two inaccurate conceptions blocked meaningful solvers from generating a correct answer, and four inaccurate conceptions accompanied a meaningfully solving that generated a correct answer. These noteworthy accurate and inaccurate conceptions are discussed here along with some instructional implications. Finally, some research questions that emerge from this study are presented.

Accurate Conceptions

MG alone seemed to use completely accurate conceptual knowledge to solve the problem. Moreover, during the interview, he alone knew all of the accurate conceptions, and he alone exhibited no inaccurate conceptions about osmosis. In as much as he might have used all of the accurate conceptions on the list in solving the problem, any or all of them might be usefu' to others. Thus teachers and students could use Table 1 as a check list. Before introducing the problem, teachers could see whether they have provided opportunities for their students to construct these conceptions, and students could check their understandings against this list.

Accurate Conceptions 7 and 8, however, seem to have been especially important to these meaningful solvers. In fact, only those who knew both conceptions generated a correct answer. To (intentionally) generate a correct graph, solvers must make two inferences:

1. The rate of osmosis into the funnel continuously decreases.

2. The problem condition reaches an osmotic equilibrium.

Accurate Conceptions 7 and 8 are useful for warranting both inferences. For example, from GT's protocol:

> I think it would start out fast and slow down as it went 'cause as the air pressure and the force of gravity pulled down on the solution level in the tube, it would slow down and eventually stop at the equilibrium state.

In fact, these conceptions about hydrostatic pressure seem to have been crucial to GT because he did not know prior to solving the problem that the rate of osmosis regularly decreases, i.e., Accurate Conception 9.

Similarly, JD, EB and RG might have generated a correct answer if they had known Accurate Conceptions 7 and 8. RG might have doubted Inaccurate Conception 4 and been able to make the first inference. That is, she might have realized that with the increasing opposition to osmosis, the rate would have to decrease rather than stay constant. JD and EB might have doubted Inaccurate Conception 8 and been able to make the second inference. That is, they might have realized that with the increasing hydrostatic pressure, the problem condition would have to reach an osmotic equilibrium even though the water concentrations were still unequal.

Hydrostatic pressure relations are important in most osmotic systems, including the problem condition

(Murray, 1983). Yet, despite the fact that many high school biology texts display such osmometer-like apparatus, they rarely mention pressure relations (Friedler et al., 1985). It is not surprising then that only 6 of the 14 outstanding science students in this study could solve the problem meaningfully, and only 3, correctly as well. Most students are confused about the effects of pressure (Friedler et al., 1987; Murray, 1983; Okeke & Wood-Robinson, 1980). Therefore teachers need to look beyond the typical textbook for useful representations of hydrostatic pressure in osmotic systems, and textbooks need to provide a more thorough explanation of hydrostatic pressure relations.

<u>Inaccurate Conceptions That Blocked a Correct Answer</u>

Inaccurate Conceptions 4 and 8 each blocked meaningful solvers in this study from generating a correct answer to the problem under study. Inaccurate Conception 4, the conception that water osmoses at a constant rate, blocked RG from making the first inference. Thus she generated a graph with a constant rather than decreasing positive slope. Inaccurate Conception 8, the conception that the concentrations of water across the membrane must be equal at osmotic equilibrium, blocked JD and EB from making the second inference. Thus they generated graphs with a horizontal asymptote rather than a horizontal tangent.

Teachers can therefore use the problem under study to identify students with either of these two inaccurate conceptions.

In fact, both inaccurate conceptions may be quite prevalent. Friedler et al. (1987) report that most students believe that equal concentrations are necessary for an osmotic equilibrium. Moreover, although the study undertaken here is the first report of Inaccurate Conception 4, the conception of a constant osmotic rate may also be quite prevalent. It is a plausible assumption that is logically consistent with other prevalent inaccurate conceptions (Friedler et al., 1987; Johnstone & Mahmoud, 1980b; Murray, 1983; Okeke & Wood-Robinson, 1980).

Inaccurate Conceptions That Accompanied a Correct Answer

Other prevalent inaccurate conceptions about osmosis, however, accompanied (and therefore could be concealed by) a correct answer to the problem under study. GT generated a correct answer despite Inaccurate Conception 1; NK, despite Inaccurate Conceptions 1, 2, 5, and 7. Various researchers have documented the prevalence of Inaccurate Conceptions 1, 2, and 5 (Friedler et al., 1987; Johnstone & Mahmoud, 1980b; Murray, 1983; Okeke & Wood-Robinson, 1980). Inaccurate Conception 7, though not expressly mentioned in the literature, is a hybrid of Inaccurate Conceptions 2 and 8, both of which have been reported as prevalent.

NK generated a correct answer without understanding the significance of random particulate motion and concentration, concepts that are so fundamental to osmosis. Thus, even for a meaningful solver of this problem, a correct answer is not necessarily an indication of a thorough understanding. Teachers therefore should provide opportunities for students to explain their solvings (as well as to display their answers) and should attend particularly to their students' understandings of random particulate motion and concentration.

The problem under study is useful for teaching students about osmosis. Solvers have the opportunity to explore a great deal of complex conceptual knowledge about osmosis. Moreover, the problem has the capacity to identify solvers with certain prevalent inaccurate conceptions. Finally, discussions in which students explain their solvings and justify their inferences are likely to generate the conceptual dissonance that promotes conceptual change (Strike & Posner, 1992).

Research Questions

Strike and Posner's (1992) focus on conceptual ecologies provides a useful framework for generating new research questions from the results of this study. For example, how do a solver's various accurate and inaccurate conceptions interact during problem solving? How does the solving of a problem provide the opportunity for a solver to formulate a new conception? NK understood the concept of concentration but abandoned it as senseless in the context of her teleological/anthropomorphic view of osmosis. Why did she not abandon instead her teleological/anthropomorphic view of osmosis? Moreover, how did she come to formulate a conception based on amounts rather than concentrations?

How does a belief in Inaccurate Conception 4 impact on one's capacity to learn Accurate Conceptions 7 and 8? That is, how does a belief that the rate of osmosis is constant affect one's capacity to learn how the weight of the solution generates a pressure that opposes osmosis? Or, how does a belief in Inaccurate Conception 8 impact on one's ability to learn Accurate Conceptions 7 and 8? That is, how does a belief that equal concentrations are necessary for an osmotic equilibrium affect one's capacity to learn about the relationship between hydrostatic pressure and osmotic equilibria?

And finally, what kinds of epistemologies do solvers use to resolve the conceptual conflicts that arise as the various accurate and inaccurate conceptions interact during problem solving? Indeed, osmosis is a sufficiently rich and important domain to be an appropriate focus for such research questions.

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Table 1

List of Accurate Conceptions About Osmosis

1. Osmosis is the result of random motion.
2. Osmosis is the net movement of water.
3. The direction of osmosis is from regions of higher to regions of lower water concentration.
4. The concentration gradient of water affects how much water osmoses.
5. The concentration gradient decreases during osmosis.
6. The osmosis of water into a confined vessel increases turgor pressure.
7. Increasing the height of the column of solution increases the hydrostatic pressure on the membrane.
8. When a solution and water are separated by a selectively permeable membrane, pressure against the solution side of the membrane opposes osmosis.
9. The rate of osmosis decreases over time.
10. The rate of osmosis varies directly with the concentration gradient of water.
11. Water crosses the membrane both ways at the same rate during osmotic equilibrium.
12. Osmotic equilibrium can be brought about by increasing the hydrostatic pressure on the solution, decreasing the concentration gradient, or both.

Table 2

List of Inaccurate Conceptions About Osmosis

1. Water teleologically/anthropomorphically osmoses to equalize either the amounts or concentrations of water.
2. Different amounts of water across the membrane, rather than different concentrations, drive osmosis.
3. Water cannot osmose against a pressure gradient.
4. The rate of osmosis is constant.
5. Water molecules cease moving across the membrane at osmotic equilibrium.
6. The hydrostatic pressures across the membrane must be equal at osmotic equilibrium.
7. The amounts of water across the membrane must be equal at osmotic equilibrium.
8. The concentrations of water across the membrane must be equal at osmotic equilibrium.

Table 3

Inventory of Meaningful Solvers' Accurate Conceptions About Osmosis

	Solvers					
	Correct			Incorrect		
Conception	MG	NK	GT	JD	EB	RG
1	+			+		
2	+			+		+
3	+		+	+	+	
4	+		+	+	+	
5	+	+	+	+	+	
6	+	+	+	+		
7	+	+	+			
8	+	+	+			
9	+	+		+	+	
10	+		+		+	+
11	+			+		+
12	+		+			

Note. The symbol + means that the substance of the conception was expressed at most of the appropriate times during the interview.

Table 4

Inventory of Meaningful Solvers' Inaccurate Conceptions About Osmosis

	Solvers					
	Correct			Incorrect		
Conception	MG	NK	GT	JD	EB	RG
1		X	X		X	X
2		X				X
3					X	X
4						X
5		X				
6						X
7		X				X
8				X	X	

Note. The symbol X means that there is evidence for the substance of the conception during the interview.

A Problem about Osmosis

The figure below is a diagram of an inverted thistle top funnel which can be used to demonstrate osmosis. At the beginning of an experiment there is a dilute solution of sugar and water inside the funnel. An inelastic membrane permeable only to water has been fitted across the immersed funnel opening. The funnel is surrounded by pure water.

Make a graph to show how the solution level in the stem of the funnel changes with time.

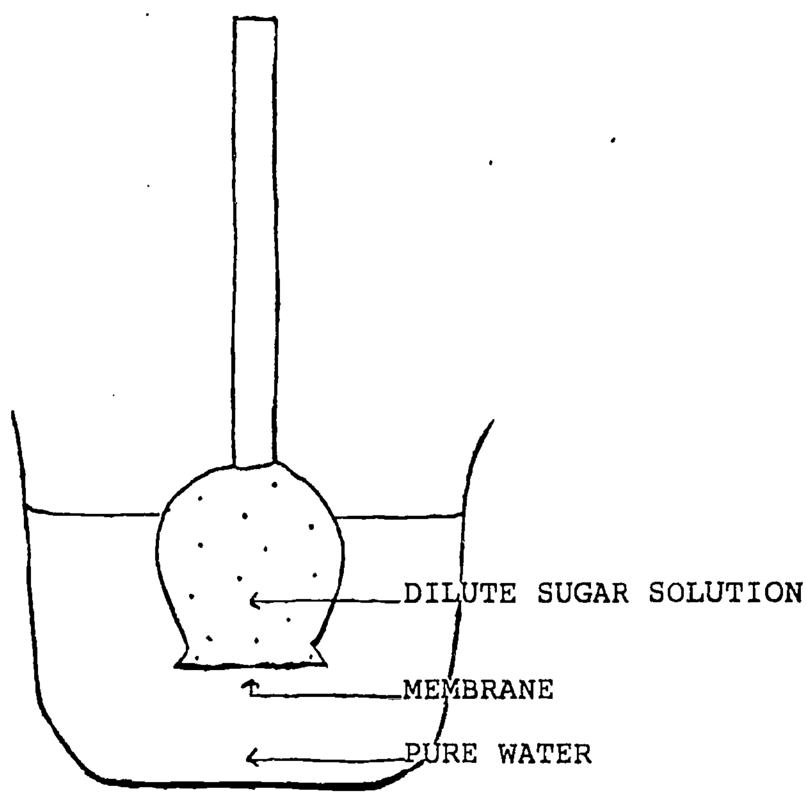

Figure 1. Statement of the problem under study.

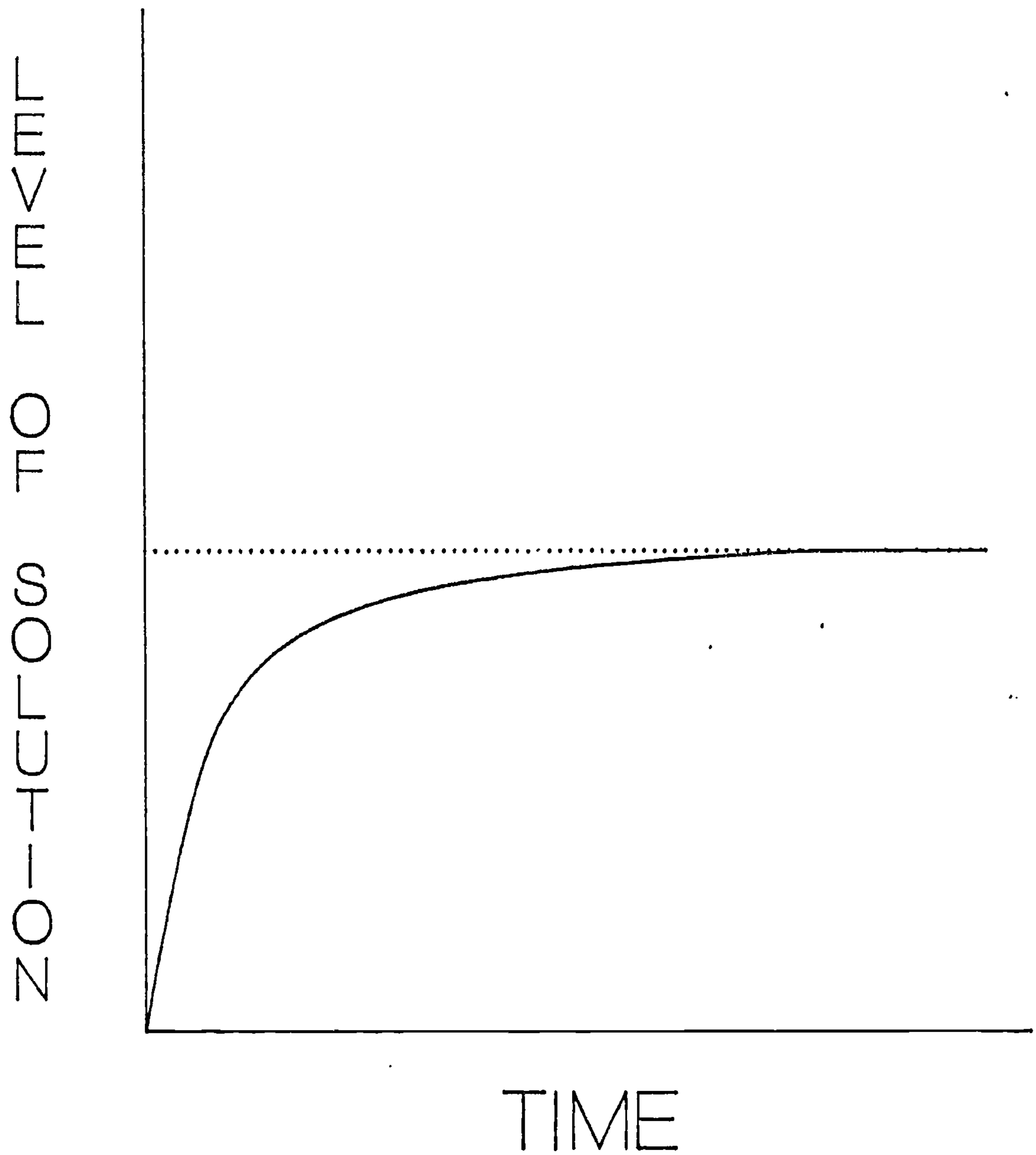

Figure 2. The model graph: Solution level as a function of time.

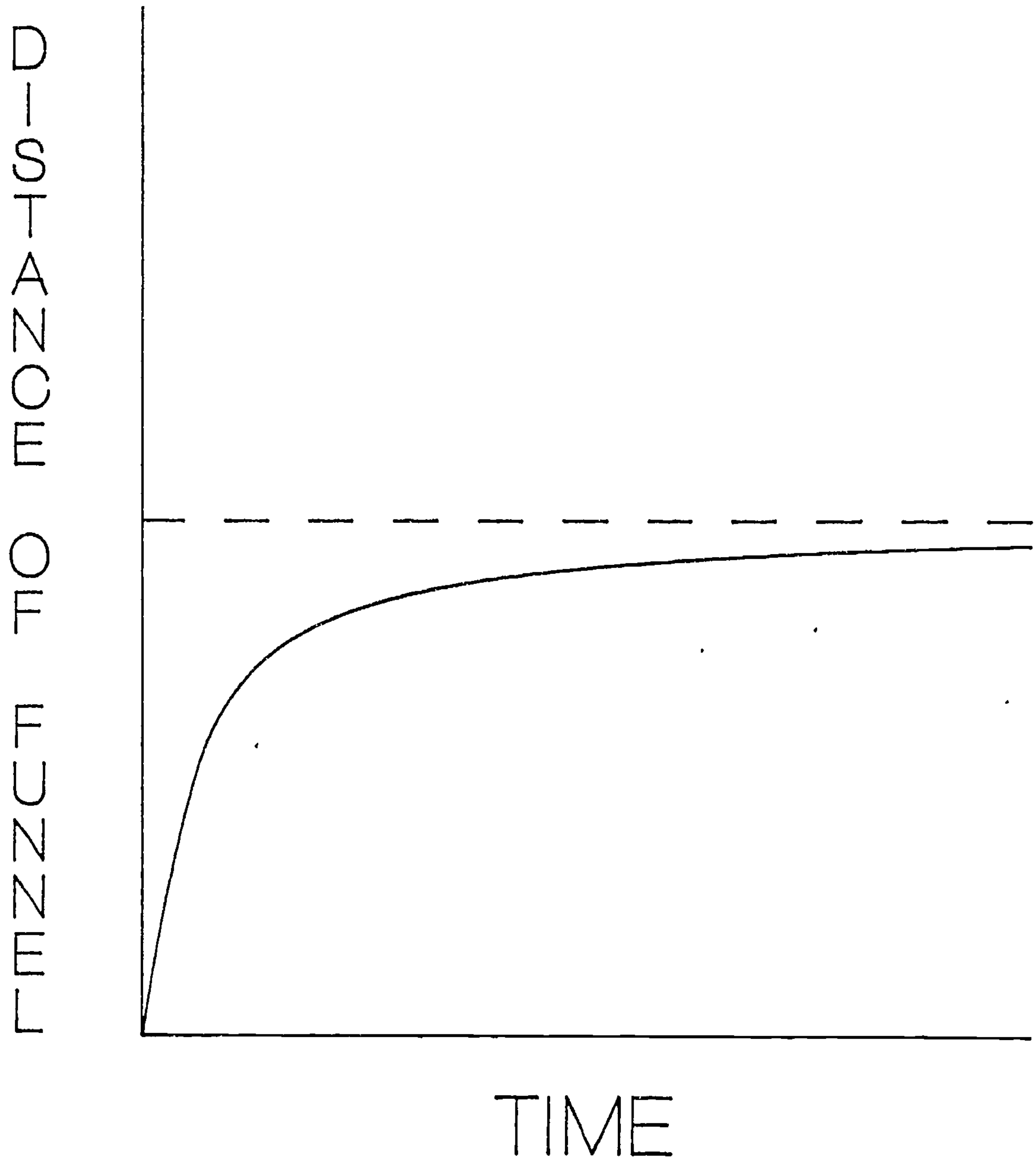

Figure 3. EB's graph.

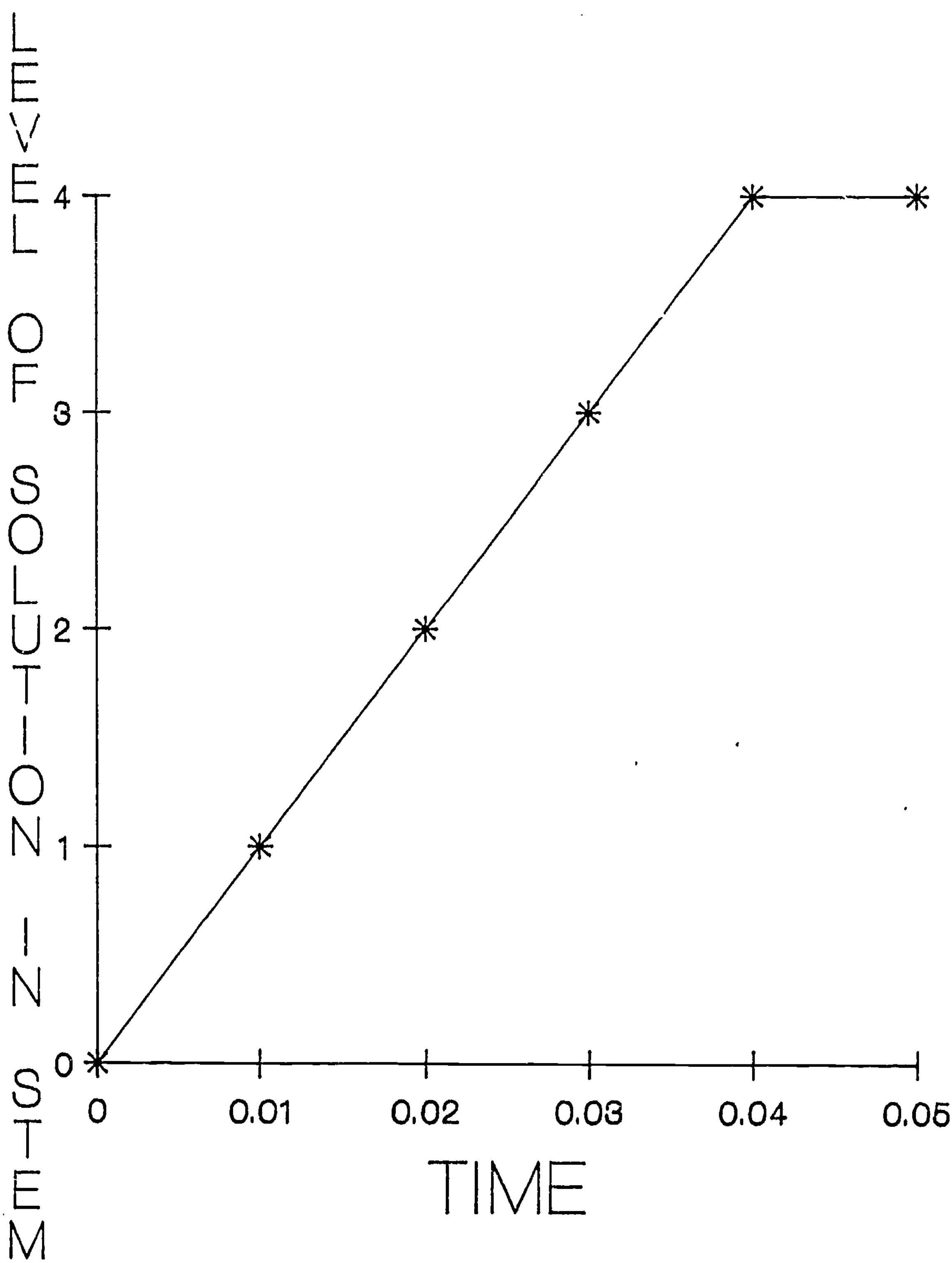

Figure 4. RG's graph.